UNIVERSITE DE LAUSANNE - FACULTE DE MEDECINE

Division de Physiologie clinique
Directeur : Professeur Eric Jéquier

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Institut de Physiologie
Directeur : Professeur Michel Dolivo

METABOLIC EFFECTS OF A MIXED AND A HIGH CARBOHYDRATE LOW FAT DIET IN MAN MEASURED OVER 24 H IN A RESPIRATORY CHAMBER

T h è s e

présentée à la Faculté de Médecine
de l'Université de Lausanne
pour l'obtention du grade de docteur en médecine

par

Michel HURNI

Médecin diplômé de la Confédération Suisse
Originaire de Gurbrü (BE)

1981

Je voudrais exprimer ma reconnaissance à Monsieur le Professeur Eric Jéquier qui m'a permis d'accomplir ce travail sous sa direction.

Ma reconnaissance va également à Monsieur le Professeur Michel Dolivo qui m'a donné la chance de travailler dans son Institut.

Enfin, je remercie Mademoiselle Evelyne Maeder, Messieurs Bernard Burnand et Philippe Pittet pour leur collaboration, ainsi que Mademoiselle Jacqueline Braissant pour la dactylographie de ce texte.

S Y N O P S I S

1. The adaptation of the 24 h fuel mixture oxidized to the composition of the diet when modifying the carbohydrate-lipid ratio was investigated in eleven healthy volunteers (6 females and 5 males) in a respiratory chamber.

2. The subjects were first fed a mixed diet for 7 days and spent the last 24 h of the dieting period in a respiratory chamber for continuous gas exchange measurement. The fuels oxidized during a 2.5 h moderate exercise were also measured in the respiratory chamber. After an interval of 2 weeks from the end of the mixed diet period, the same subjects were fed an isocalorically high carbohydrate low fat diet for 7 days, and the same experimental protocol was repeated.

3. The diet composition markedly influenced the fuel mixture oxidized during 24 h and this effect was still present 12 h after the last meal in the postabsorptive state. However, the diets had no influence on the substrates oxidized above resting levels during the exercise. With both diets, the 24 h energy balance was slightly negative and the caloric deficit was covered by lipid oxidation.

4. The high carbohydrate low fat diet was found to stimulate energy expenditure during sleep.

5. It is concluded that (a) the composition of the diet does not influence the fuel mixture utilized for moderate exercise;

(b) the energy deficit calculated for a 24 h period is covered by lipid oxidation irrespective of the carbohydrate content of the diet; (c) high carbohydrate diet stimulates energy expenditure during sleep.

INTRODUCTION

Adaptation of energy expenditure to various energy intakes has been often studied in man (Passmore *et al.* 1955; Durnin & Norgan, 1969; Garrow, 1978; Danforth *et al.* 1978). Dauncey (1980) has recently shown that over-eating (or under-eating) for only one day induces changes in energy expenditure, and that the resting metabolic rate measured 14 h after the last meal is affected by the previous day's energy intake. However, adaptation of the 24 h fuels oxidized to the composition of the diet has received less attention. The goal of the present study was to investigate the fuel mixture oxidized over 24 h when modifying the carbohydrate-lipid ratio of the diet.

Comparison of nutrients ingested with the fuels oxidized over 24 h allows to establish a 24 h nutrients balance. Another way of studying the relationship between nutrients intake and fuels oxidized is to compare the mean respiratory quotient (RQ) measured over 24 h with the mean food quotient (FQ), i.e. the ratio of the volume of CO_2 produced over the volume of O_2 consumed for the combustion of the caloric intake (Flatt, 1978). The FQ of a balanced diet usually consumed is about 0.85, which corresponds to an energy partition of about 45, 40 and 15 % for carbohydrates (CHO), fat

and protein respectively. When the mean FQ of a 24 h caloric intake is similar to the subject's mean 24 h RQ, the fuel mixture oxidized corresponds to the CHO-fat composition of the diet.

When the 24 h RQ is smaller than the 24 h FQ, this means that the amount of lipid oxidized is larger than that ingested, i.e. there is a net endogenous lipid oxidation. Since this is the goal of obesity treatment, it is of interest to study conditions which induce a 24 h RQ lower than the 24 h FQ.

In the present study two isocaloric diets were given to healthy young men for one week, one with a high FQ (high CHO low fat diet = HCLFD), and the other with a medium FQ (balanced mixed diet = MD) in order to establish whether nutrients balance could be obtained under both diets, and to study whether the metabolic adaptation to the diet was still present 12 h after the last meal.

An additional goal of this study was to measure the fuels oxidized with both diets during a 2.5 h moderate exercise. Since prolonged exercise is known to stimulate fat oxidation (Armstrong *et al.* 1961; Ahlborg *et al.* 1974), we investigated whether subjects receiving a low fat diet may have to consume more endogenous lipid during exercise than subjects receiving a larger amount of exogenous lipid.

MATERIALS AND METHODS

Subjects

Eleven healthy medical students (6 females and 5 males) volunteered for this investigation. Their mean age was 23.6 ± 1.2 years, body weight 62.6 ± 2.9 kg. All subjects were within ±10 % of ideal body weight according to the Metropolitan Life Insurance Tables (1959).

Diets

Two types of diet, MD and HCLFD were used to obtain a desired FQ respectively of 0.84 and 0.94. Frozen foods were provided for lunches and diners, whereas subjects had several alternatives for breakfast and snacks during the day in order to keep the FQ at the desired level. Food composition analysis of the meals provided for lunches and diners were made by bomb calorimetry, whereas food tables (Souci *et al.* 1979) were used to compute food composition of breakfasts and snacks. Atwater's coefficients were utilized to obtain the energy content of the meals (Atwater & Bryant, 1899).

Experimental procedure

Each subject was first fed the MD for 7 days (Table 1). Most of them had their lunch at the Institute, whereas breakfasts,

Table 1 Composition of the diets in protein, lipid and carbohydrate (g/d), food quotient during the experimental week (a) and the experimental day (b).

	Protein (g/d)		Lipid (g/d)		Carbohydrate (g/d)		Energy intake (kJ/d)		Food-quotient	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
a) Experimental week*										
Mixed diet	89	4	92	4	227	10	8730	358	0.845	0.002
High carbohydrate low fat diet	89	3	12	0.4	383	15	8337	308	0.944	0.001
b) Experimental day										
Mixed diet	88	2	85	3	228	5	8653	176	0.849	0.003
High carbohydrate low fat diet	88	3	9.5	1	406	1	8678	515	0.948	0.002

* average of 7 days

snacks and evening meals were always taken at home. Subjects spent the last 24 h of the dieting period in a respiratory chamber for continuous gas exchange measurements. Two hours after the entrance (at 8 am) in the metabolic chamber, subjects were asked to perform a light muscular exercise i.e. pedaling at 30 W (184 kg-m/min) for 2.5 h on a bicycle ergometer (Quinton Instr.). The remainder of the day, subjects were free to do what they wanted e.g. working at the desk, sitting or lying on the bed, watching television, but no intense physical activity (e.g. gymnastic) was allowed. The subjects received their meals when in the metabolic chamber (Table 1) through an air tight communication compartment. On the morning following the 24 h spent in the chamber, subjects had their resting metabolic rate (RMR) measured for 1.5 h. After an interval of 2 weeks from the end of the MD period, the same subjects were fed the HCLFD for 7 days (Table 1). The experimental procedure was exactly the same as that described for the period of MD.

Measurements

RMR. Oxygen consumption and carbon dioxide production were continuously measured by open circuit indirect calorimetry, using a transparent ventilated hood (Jéquier, 1980), with values averaged for five minutes periods.

24 h energy expenditure (24 EE). Oxygen consumption and carbon dioxide production were continuously monitored, using a respiratory chamber whose size is 5 m long, 2.5 m wide

and 2.5 m high (Jéquier, 1980). In addition, the spontaneous physical activity was monitored using a radar system based on the Doppler effect (Schutz *et al.* 1980) and physical activity was expressed as a percentage of the time during which the subject was moving. All measurements were averaged for 30 minutes periods.

Urine samples. Urine was collected during the 24 h EE and RMR measuring periods and analysed for urinary nitrogen using the Kjeldhal method (Hawk, 1947). CHO, lipid and protein oxidation rate were then calculated as previously described (Jéquier, 1980). Urinary glucose was analysed during the 24 h EE measurement using a qualitative hexokinase method (Gluketur-test^{R}, Boehringer).

Blood samples. Blood samples were obtained in the post-absorptive state before and after the 7-day periods of the diets. Blood samples in the metabolic chamber were obtained with a specially designed set-up; the experimentator entered into the room by an air tight communication compartment breathing through a mask connected to outside air to avoid altering the air composition of the chamber. Blood samples were analysed for : blood glucose using the hexokinase method (Slein, 1965), plasma immunoreactive insuline (IRI) (Herbert *et al.* 1965), plasma free fatty acids (FFA) using the Dole & Meinertz (1960) extraction and determination of Ho (1970) as modified by Heïndel *et al.* (1974).

Statistical analysis. Results are given as mean values ± SEM. Data were analysed using the Student's test for paired data, each subject being his own control.

RESULTS

Energy balance

The mean energy intake and expenditure of the subjects during the 24 h period in the respiratory chamber are presented in Table 2. The energy content of the two diets was almost identical; 24 EE was larger than intake after both diets, resulting in a negative energy balance. It must be pointed out that the energy deficit was mainly due to the muscular exercise performed during the test. RMR values were not significantly different after the two diets, 157 ± 6 and 154 ± 5 $kJ/h.m^2$ for MD and HCLFD respectively (not shown in the Table).

FQ and RQ

The mean values of FQ, RQ during the 24 h EE, and RQ during RMR measurements (obtained after a 12 h postabsorptive state period) are also presented in Table 2. Mean RQ values for 24 h were always significantly lower than FQ values ($p < 0.05$). The RQs measured during 24 h

Table 2 Energy intake (kJ/24 h), energy expenditure (kJ/24 h) during the experimental day, food quotient, mean respiratory quotients (RQ) measured during 24 h and during resting metabolic rate (RMR).

	Energy intake kJ/24 h		expenditure kJ/24 h		Difference of the means		Food-quotient		RQ during the 24 h of measurement		RQ (RMR)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Mixed diet	8653	176	10074	392	-1421	443*	0.849	0.003	0.795†‖	0.007	0.800†§	0.008
High carbohydrate low fat diet	8678	515	10591	502	-1913	524*	0.948	0.002	0.879‡‖	0.005	0.856‡§	0.007

* Difference of the means between energy intake and expenditure; MD versus HCLFD, not significant

‖ Mean RQ during the experimental day; MD versus HCLFD, $p < 0.001$

§ Mean RMR RQ; MD versus HCLFD, $p < 0.001$

† Comparison between mean RQ during the experimental day and mean RMR RQ for the MD, not significant

‡ Comparison between mean RQ during the experimental day and mean RMR RQ for the HCLFD, $p < 0.05$.

or during RMR were both significantly higher with the HCLFD than with MD respectively. The coefficient of variation of RQ values during the 24 EE measurement was calculated for each subject : there was no statistical difference between these coefficients of variation obtained after the two diets.

Substrates balance

In Table 3, substrate oxidation rates during the 24 h in the respiratory chamber are compared to the substrates ingested. Protein oxidation rates were not affected by the type of diet eaten. On the other hand, lipid and CHO oxidation rates were significantly different ($p < 0.001$), depending on the kind of diet consumed. When fed the MD, subjects oxidized in average 160 ± 11 g lipid and 165 ± 15 g CHO during the 24 h in the chamber, whereas when fed the HCLFD subjects showed an almost two fold increase in CHO oxidation rate 359 ± 15 g with a concomittent decrease in lipid utilization 90 ± 8 g. Whatever the diet consumed, lipid utilization was always larger than lipid intake, whereas the amount of CHO oxidized was smaller than CHO intake.

The diet's composition also influenced the substrates utilized during RMR, i.e. more CHO was oxidized with HCLFD than with MD; the reverse was true for the lipid oxidation.

Table 3 Substrates ingested and oxidized (g/24 h) during the experimental day for the mixed diet (MD) and the high CHO low fat diet (HCLFD). Substrates oxidized during RMR (mg/min) for MD and HCLFD.

	Ingested (g/24 h)		Oxidized (g/24 h)		Difference between the means	1 h RMR (mg/min)	
	Mean	SE	Mean	SE		Mean	SE
			a) Mixed diet				
Protein	88	2	77*	6	+11	50†	9
Lipid	85	3	160‡	11	-75	60§	7
Carbohydrate	228	5	165‖	15	+63	69¶	8
			b) High carbohydrate low fat diet				
Protein	88	3	71*	7	+17	45†	8
Lipid	9.5	1	90‡	8	-80.5	39§	4
Carbohydrate	406	1	359‖	15	+47	117¶	11

* Protein oxidized during 24 h; MD versus HCLFD, not significant

‡ Lipid oxidized during 24 h; MD versus HCLFD, $p < 0.001$

‖ CHO oxidized during 24 h; MD versus HCLFD, $p < 0.001$

† Protein oxidation rate during RMR; MD versus HCLFD, not significant

§ Lipid oxidation rate during RMR; MD versus HCLFD, $p < 0.005$

¶ CHO oxidation rate during RMR; MD versus HCLFD, $p < 0.001$

Fuel utilization during exercise

The energy expended and the substrates oxidized for the exercise only, are presented in Table 4. In this case, the substrates oxidized represent the net increase above the mean oxidation rates measured during the resting period. The proportion of lipid and CHO oxidized for the exercise only was not influenced by the composition of the diet consumed, and was almost identical in the two experimental conditions. The proportion of protein in the fuel oxidized during the exercise was very small and represented about 1 g for each diet.

Energy expenditure during sleep

Total energy expenditure during the period of sleep only is presented in Figure 1. Determination of the sleeping periods at night was achieved by considering only those periods where the mean spontaneous physical activity (measured by the radar system) was between 0 and 1 % of the 30 min periods; the average sleeping period was 6 h 18 min ± 12 min. Energy expenditure was significantly lower with MD than with HCLFD ($p < 0.005$). The net mean difference between the two experimental conditions was 148 ± 40 kJ for the sleep period.

Table 4 Energy expenditure (kJ/2.5 h) and lipid + CHO oxidized (g/2.5 h) for the exercise only. The energy expenditure and substrates oxidized represent the net increase above the mean resting value.

	Mixed diet		High carbohydrate low fat diet		Statistical significance of difference between means
	Mean	SE	Mean	SE	
Energy expenditure	1887	78	1785	61	NS
Lipid	25	2.4	23	2	NS
Carbohydrate	56	7	55	5	NS

NS, not significant

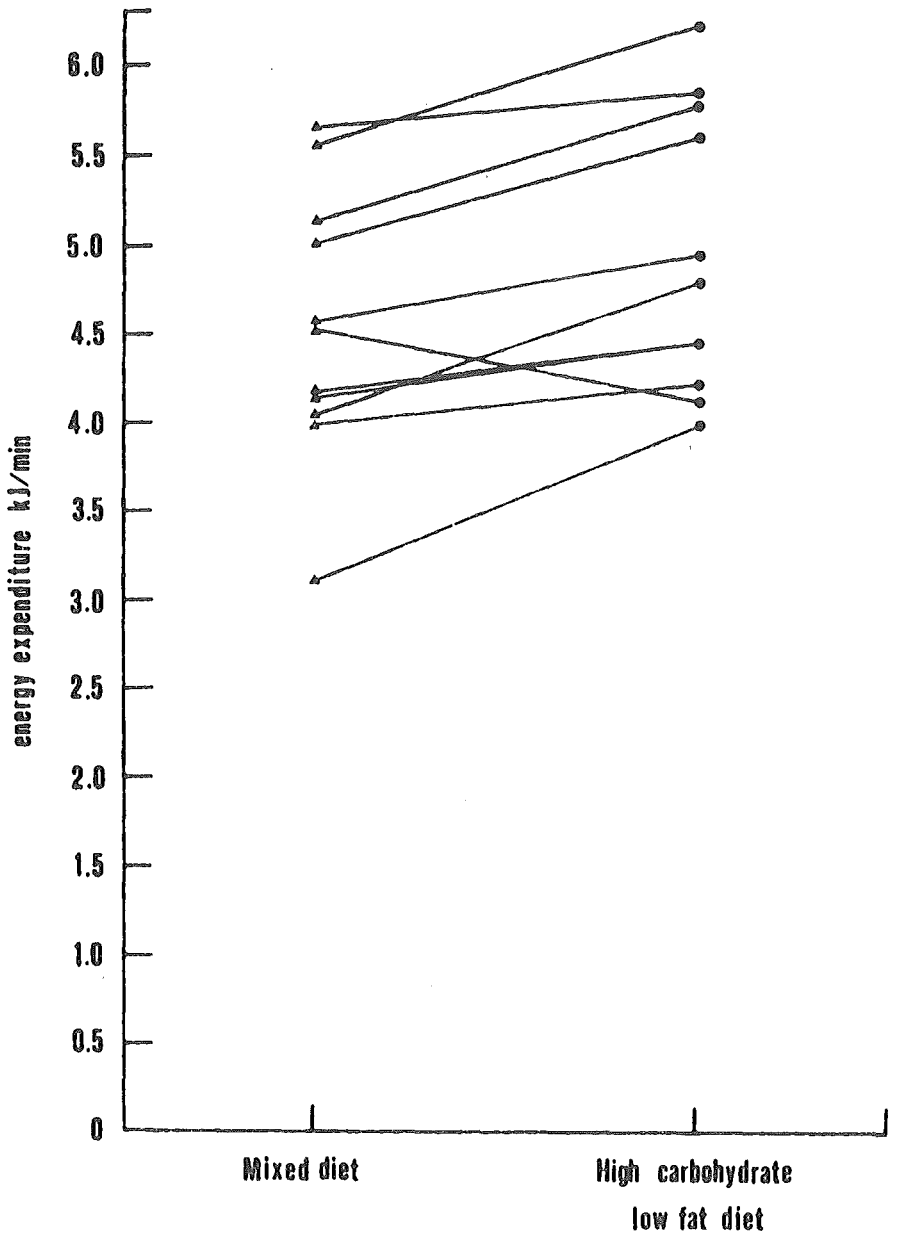

Fig. 1. Comparison of energy expenditure (kJ/min) during sleep only. Mixed diet (▲); high CHO low fat diet (●). Statistical significance : $p < 0.005$.

Blood parameters

There was no difference between postabsorptive blood glucose of day 1 and after 1 week of MD or HCLFD respectively; nor was any difference of postabsorptive blood glucose between the two diets after 7 days (Table 5). During exercise blood glucose decreased slightly below fasting levels and similarly on both diets.

Postabsorptive plasma FFA levels were similar after one week of both diets (Table 5). During exercise, plasma FFA levels rose similarly after the two diets.

Insulin postabsorptive levels were significantly higher with HCLFD than with MD after one week of diet ($p < 0.05$) and after the 24 h measurement ($p < 0.02$), but it remained within the physiological range. During the exercise there was a similar decrease in insulin levels with both diets. No subject had urinary glucose after either diet.

DISCUSSION

The purpose of this investigation was to study the adaptation of the fuels oxidized at rest and during exercise after 7 days of high CHO low fat diet. The distribution of the fuel mixture oxidized was influenced by the composition of the diet (Table 3) in spite of similar plasma levels of glucose and FFA. The metabolic adaptation to the HCLFD

Table 5 Blood glucose (mmol/l) free fatty acids (FFA) (μmol/l) and immunoreactive insulin (IRI) (μU/ml) before and after the experimental week, before, during and after the exercise period.

	BLOOD GLUCOSE mmol/l		FFA μmol/l		IRI μU/ml	
	Mean	SE	Mean	SE	Mean	SE
Postabsorptive state before the experiment						
Mixed diet	4.7	0.1	559	92	16.7	1.7
High CHO low fat diet	4.9	0.1	627	101	18.9	2.2
Postabsorptive state after the experimental week						
Mixed diet	4.7	0.1	684	109	15.1*	1.5
High CHO low fat diet	4.7	0.1	530	75	19.8*	1.8
Before the exercise						
Mixed diet	4.4	0.2	568	72	15.8	2.5
High CHO low fat diet	4.0	0.2	418	168	18.0	1.9
After 1.5 h exercising						
Mixed diet	4.2	0.1	1002	139	9.1	1.1
High CHO low fat diet	4.3	0.1	928	103	10.8	1.4
End of exercise (2.5 h)						
Mixed diet	4.3	0.1	1625	169	10.4	1.9
High CHO low fat diet	4.4	0.1	1538	164	12.6	1.6
Postabsorptive state after the 24 h of measurement						
Mixed diet	4.8	0.1	460	60	12.3†	1.0
High CHO low fat diet	4.8	0.1	369	41	15.3†	1.3

*IRI after the experimental week; MD versus HCLFD, $p < 0.05$

†IRI after the 24 h of measurement; MD versus HCLFD, $p < 0.02$

was not only present during the 24 h measurement period, but it persisted in the morning postabsorptive state, 12 hours after the last meal.

During the 24 h test period, the subjects were in negative energy balance due mainly to the 2.5 h exercise. It is interesting to note that with both MD and HCLFD :

(1) The energy deficit was covered by a similar amount of endogenous fat oxidized.

(2) The energy provided for the exercise was about 50 % from CHO and 50 % from fat oxidation.

(3) A positive CHO balance was observed in spite of the energy deficit.

These data show that the composition of the diet has no influence on the extra-energy consumed to cover a 24 h energy deficit : with both MD and HCLFD, this deficit was covered by using endogenous fat. The HCLFD, which is known to maintain elevated CHO stores in liver (Hultman & Nilsson, 1971) and muscles (Bergström *et al.* 1967) did not favour CHO utilization during the 2.5 hour exercise at moderate intensity. The tendency to keep a positive CHO balance with both diets under conditions of negative energy balance may be a transient phenomenon. It is not possible to store repeatedly large amounts of CHO since the storage capacity of glycogen is limited (Hildes *et al.* 1949). However, Passmore & Swindels (1963), Hermansen *et al.* (1967), Saltin & Hermansen (1967) and more recently Acheson *et al.* (1979) have supported the view that the capacity to store CHO

in man might be larger than usually described. In this study, RQs above 1 were not observed indicating that, despite a large CHO intake, there was no evidence of a net gain of fat by lipogenesis. These results are in agreement with those of Furnass (1960), Passmore & Swindels (1963) and Acheson *et al.* (1979) who also found limited net conversion of CHO into fat after large CHO intakes.

Numerous studies have delt with the fuels consumed during exercise in relation to ingested diets (Christensen & Hansen, 1939; Bergström *et al.* 1967; Pruett, 1970a). Pruett (1970a), Ahlborg *et al.* (1974) and Astrand & Rodhal (1970) showed that in low intensity long duration exercise, about half of the energy proceeds from fat and half from CHO. In this study, we found a similar fuel distribution, and this was not affected by the adaptation to either HCLFD or MD. Ingestion of HCLFD did not potentialize CHO utilization for the exercise, and consequently lipids were not spared with HCLFD. Moreover, the changes in plasma levels of FFA and IRI during exercise were similar with both diets as also reported by Pruett (1970a,b). These results confirm the fact that prolonged exercise at low intensity is performed by using both fat and CHO, provided that CHO stores are sufficient. Only when CHO stores have been previously depleted (Ravussin *et al.* 1980), fat oxidation becomes much more important than CHO metabolism. It is therefore beneficial to include moderate physical activity in a weight

maintenance program in order to favour fat oxidation as suggested by Flatt (1978) and Nelson (1978).

With similar 24 h energy intake, there was a tendency to consume more energy with HCLFD than with MD, but the difference was not significant over 24 hours (Table 2). However, when computing the energy expenditure during the sleeping time, the subjects with HCLFD expended significantly more energy than when receiving the MD. It is not possible to explain the lower energy expenditure due to MD by an acclimatization to the respiratory chamber, since the MD test was performed first. The reasons of a higher energy expenditure during sleep with HCLFD are unclear. Wurtman & Fernstrom (1975) suggested that brain tryptophan and serotonin levels could rise in humans following insulin injection or CHO consumption as observed in rats. This might induce changes in the pattern of the REM (rapid eye movements) and NREM (non rapid eye movements) sleep periods. An increase in the duration of NREM would imply a longer period of time with elevated muscle tone and consequently a higher energy expenditure. Furthermore, effects of CHO on sympathetic activity have been reported by De Haven *et al.* (1980). They suggested that underfeeding in humans or rats is accompanied by a decreased sympathetic activity which was due primarily to elimination of dietary CHO rather than a reduction in total calories.

Landsberg & Young (1978) described a rise in norepinephrine turnover in rats fed with a high sucrose diet. We have

recently observed an increased urinary catecholamine excretion in subjects receiving a high CHO diet (unpublished observation). Thus, an increase in sympathetic activity might be one reason explaining the elevated energy expenditure observed with HCLFD.

In conclusion, the diet composition markedly influenced the substrates oxidized during 24 hours, and this effect was still present 12 hours after the last meal in the postabsorptive state. The fuel mixture used for a prolonged exercise was not modified by the previously ingested diets, 50 % of the energy proceeding from fat and 50 % from CHO under both MD and HCLFD. Finally, HCLFD was found to stimulate energy expenditure during sleep.

The authors acknowledge the technical and secretarial assistance of Ms E. Maeder and J. Braissant and Nestlé-Findus for providing the frozen meals.

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